EFFECT OF SHADE ON TEMPERATURE MITIGATION AND CANOPY ASSIMILATION OF COFFEE AGROFORESTRY SYSTEMS

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Introduction

Modern agriculture is essential for human development but crop production levels in many regions are threatened by climate change (Bugmann et al., 2010). Climate change is resulting in more frequent extreme events (Bugmann et al., 2010) such as increased (occurrences and/or strength) drought, heavy rainfall, high temperatures, tropical cyclones (Stocker et al., 2013), fires at mid- to high-latitudes (Moritz et al., 2012) and pest outbreaks (Allen et al., 2010). Consequently, it is essential to adapt agricultural systems to new conditions if production and environmental benefits are to be maintained.

Genetic improvements form part of the solution to mitigate impacts in annual species, but this is more difficult for long-rotation species used in tree-based agriculture and silviculture. This paper assumes that the promotion of agroforestry has the potential to mitigate and provide adaptation to climate change. Therefore, investigating the performance of different agroforestry management strategies is a key priority as management can influence system responses (Battles et al., 2008) and modify competitive relationships, composition and choice of species (Linder, 2000). To do so, field experiments and modelling are the two main solutions. As most trees take decades to mature, and the number of possible management practices and/or stand compositions is large even when only two species are considered (Porté and Bartelink, 2002), field experiments alone will be overly expensive, complex and time-consuming. Therefore, computer models have to be used jointly to explore the numerous strategies in less time and effort (Bohn et al., 2014; Palma et al., 2007). Furthermore, modelling processes that describe tree growth and the harvest of tree components (such as fruits, wood, and sap) allow us to better understand the mechanisms involved and their interactions, and to predict their response to climate changes. Thus, modelling could improve our knowledge and be our basis to the guidance of the setting of future experimental cultivations.

Considering all these challenges, our research project ANR Agrobiosphère MACACC (ANR-13-AGRO-0005) combines field experiments, numeric simulations and econometrics. The system considered was agroforestry with coffee arabica plantations in Tarrazu (Costa Rica) grown under shade trees. *Coffea arabica* is a perennial plant which grows naturally under unfrosted elevated tropical forest. Beans can develop from two to three year old shoots, which are pruned every five years to maintain production. Coffee can be grown in full sun to promote mass production, but the increase in canopy temperature often decreases the maturation duration and coffee quality (Martins et al., 2014).

Coffee growth and fruit production are particularly sensitive to high temperatures and water availability, and previous studies predict large future losses of production (Bunn et al., 2014; Craparo et al., 2015; Oijen et al., 2010) or area cover (Baca et al., 2014). An alternative is to grow coffee in agroforestry systems, under shade trees with varying density. This technique allows a better bean maturation and quality, and increased adaptation options in response to climate change (Lin, 2007; Luedeling et al., 2014).

Material and methods

The research project was focused on studying different management options responses to sites properties and climate in order to secure future coffee production (**Table 3**). The management options were coffee cultivar, shade trees density and species (**Figure 6**). Two coffee variety were used: usual *Coffea arabica* var. Caturra and a F1 hybrid crossbreeding between *Coffea arabica* and a wild Sudano-Ethiopian strain (Bertrand et al., 2005) which has very promising production, disease and drought resistance (Jarri, 2012; Khac, 2012). Also, three shade options were tested with different densities: coffee grown in full sun (no shade and no shade trees), under *Erythrina poeppigiana* (200-400 trees ha^{-1}) or *Cordia alliodora* (50-125 trees ha^{-1}). The first shade tree species is from the *Fabaceae* family and can fix nitrogen. It is pruned twice a year in order to optimize light interception by the coffee to promote flowering. The *Cordia* species grows quickly and can maintain a high canopy cover and it can be harvested for wood when the crop cycle ends.

Table 3: Simulations parameters: climate, plot properties and management options.

Climate		Coffee variety		Shade (species and density)		Plot age (years)
RCP 4.5	X	Caturra	X	Full sun: 0	X	1 2 35
RCP 8.5		Hybrid		*Erythrina poeppigiana* Low: 200/250 High: 350/400 *Cordia alliodora* Low: 50/75 High: 100/125		

The site at Tarrazu is affected by a Pacific climate, and models for future climate (AR5, statistically downscaled) predict an increase of air temperature and similar rainfall levels (Figure 6), which could lead to coffee flower buds abortion (Martins et al., 2014).

Two numeric models were coupled for this study. The first model, a tree-scale three dimensional process-based model (MAESPA, Duursma and Medlyn (2012)) was used for diffuse and direct extinction coefficients (K_{dif} and K_{dir}) and light-use efficiency (*LUE*) computation and the second one, a plot scale allocation model (GO+, Loustau et al. (2012)) for growth and yield simulations.

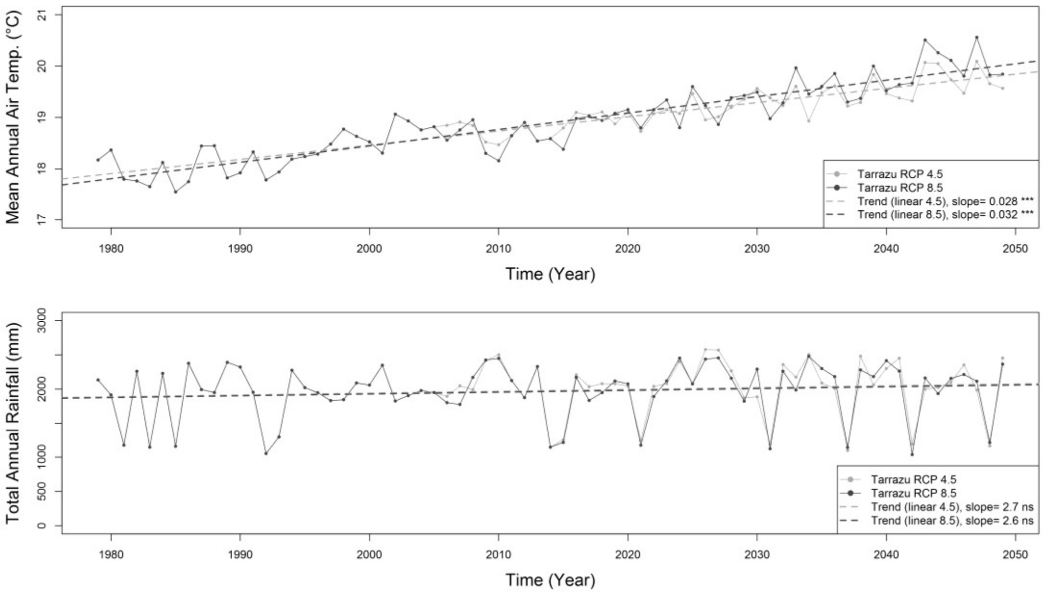

Figure 6: Mean annual air temperature and total annual rainfall downscaled to Tarrazu from historic data (1979-2005) and model predictions (2006-2049) over RCP +4.5 W m^{-2} and +8.5 W m^{-2}.

Results

First results show that management could strongly impact the main drivers of coffee growth and yield: photosynthesis, canopy temperature, or light use efficiency. **Figure 7** shows that daily coffee light use efficiency increased for coffee grown under shade trees and for higher shade trees densities (+21.4%*** to +34.9%*** for *C. alliodora* and +18%*** to +27.5%*** for *E. poeppigiana*).

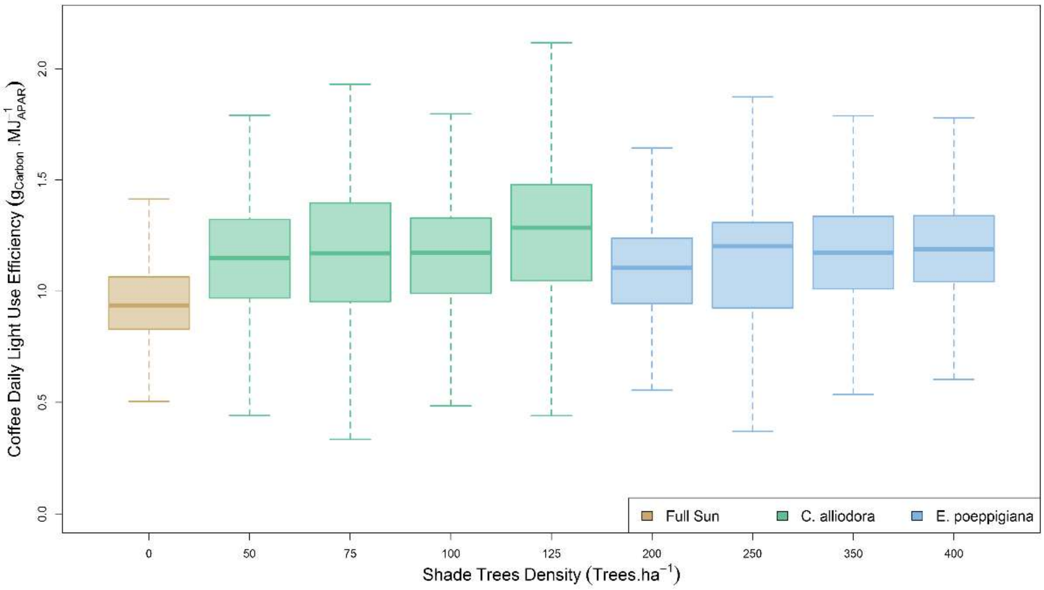

Figure 7: Coffee daily light use efficiency (gross primary production/absorbed PAR) according to shade trees density.

Furthermore, it appears (**Figure 8**) that only the *C. alliodora* planted at high densities was able to significantly reduce the maximum coffee canopy daily temperature based on recent temperatures (-3.3°C** for 75 trees ha^{-1} to -4.5°C*** for 125 trees ha^{-1}) and predicted future conditions (-3.4°C*** to -4.7°C*** respectively).

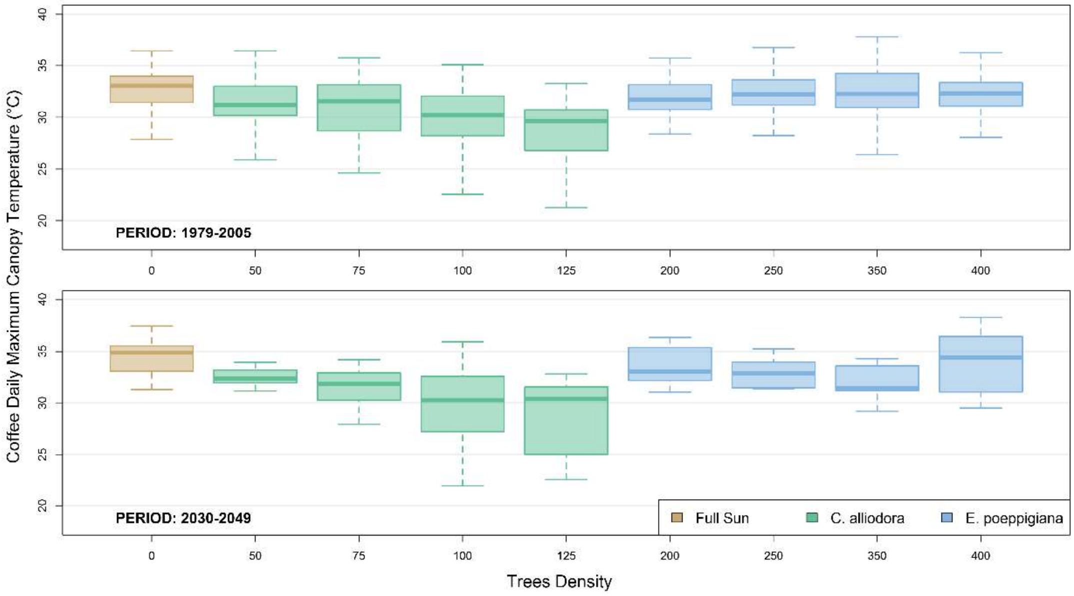

Figure 8: Simulated daily canopy maximum temperature comparison between full sun and two shade tree species at different densities for historic and future climate and CO_2 conditions (RCP: +4.5 W m^{-2}).

Discussion

It is proposed that the modelled results can be used to guide farmers on the best shading options to be adopted. The guidance should take into account management impacts on coffee canopy temperature, coffee fruit and timber yield, carbon balance and water use efficiency of past and future coffee growth cycles, under the two contrasted scenarios (+4.5 W m^{-2} and +8.5 W m^{-2} representative concentration pathways).

These first results could help stakeholder adapt their plantations to future conditions whilst minimising current production losses. For example, increasing efficiency of shade management buffering with increasing temperatures could encourage stakeholders to grow coffee plantations under high coverage shade trees without pruning (e.g. *C. alliodora*), because even low densities can reduce maximum daily canopy temperature without the expense of high tree densities or intensive pruning of shade trees.

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